The Distribution and Structure of Soft-Bottom Macrobenthos in Puget Sound in Relation to Natural and Anthropogenic Factors[1]

Roberto J. Llansó
Washington State Department of Ecology

Introduction

The Marine Sediment Monitoring Program (MSMP), a component of the Puget Sound Ambient Monitoring Program (PSAMP), was established in 1989 to measure sediment quality conditions throughout the Puget Sound region (Puget Sound, Hood Canal, the Strait of Georgia, and the Strait of Juan de Fuca). The program focuses on the Triad approach for sediment monitoring (Chapman and Long, 1983). The Triad integrates sediment chemistry, toxicity, and benthic infauna in determining sediment quality.

The MSMP has focused on ambient conditions away from point sources of pollution. Results from the first seven years of monitoring data indicated that sediment contamination at most sampling stations was low or absent (Llansó et al., 1998). Only at some specific areas associated with industrial or urban centers did sediments show moderate chemical concentrations. With few exceptions, these concentrations were below Washington State Sediment Quality Criteria. Other state and federal programs in Puget Sound are monitoring conditions near sources of pollution where sediment contamination is substantial. These programs have the need for the identification of reference conditions to which data from polluted sites can be compared.

The objective of the present study is to characterize benthic macro-invertebrate communities in non-degraded habitats of Puget Sound. Once the characteristics of these communities are known, reference conditions and criteria can be established to distinguish degraded from non-degraded habitats. Also, of interest is the identification of potential natural stresses that may structure benthic communities in Puget Sound and which may constitute confounding factors in pollution monitoring efforts.

Methods

Benthic organisms were sampled in March–April 1989–1993 at 76 monitoring stations located throughout Puget Sound, Hood Canal, and the Straits of Georgia and Juan de Fuca (Figures 1–2). Two types of stations were established: core stations, sampled once every year; and rotating stations, sampled once every three years in a rotating cycle between the north, central, and south Puget Sound regions.[2]

Sampling at each station consisted of five van Veen sediment grabs (0.1 m^2). The contents were washed through a 1.0-mm mesh screen using running seawater. The organisms were preserved in 10% buffered formalin in seawater, sorted and identified to species. Sediment contaminants (not presented here), total organic carbon, total sulfide, and grain size were measured from the top 2 cm of paired samples. See Llansó et al. (1998) for details on sample collection and analytical procedures.

The data files used to describe community structure in Puget Sound were first standardized to ensure common species nomenclature. Incidental and epifaunal organisms were eliminated from the data. To discern patterns in species abundance and composition, Margalef's Species Richness (SR) and Pielou's Evenness (J') were computed (Margalef, 1958; Pielou, 1966). The indices were calculated on composite samples, i.e., using the cumulative number of species in five samples. For each taxon and station, records with more than one level of identification were removed from the data files, leaving records with the lowest level of identification.
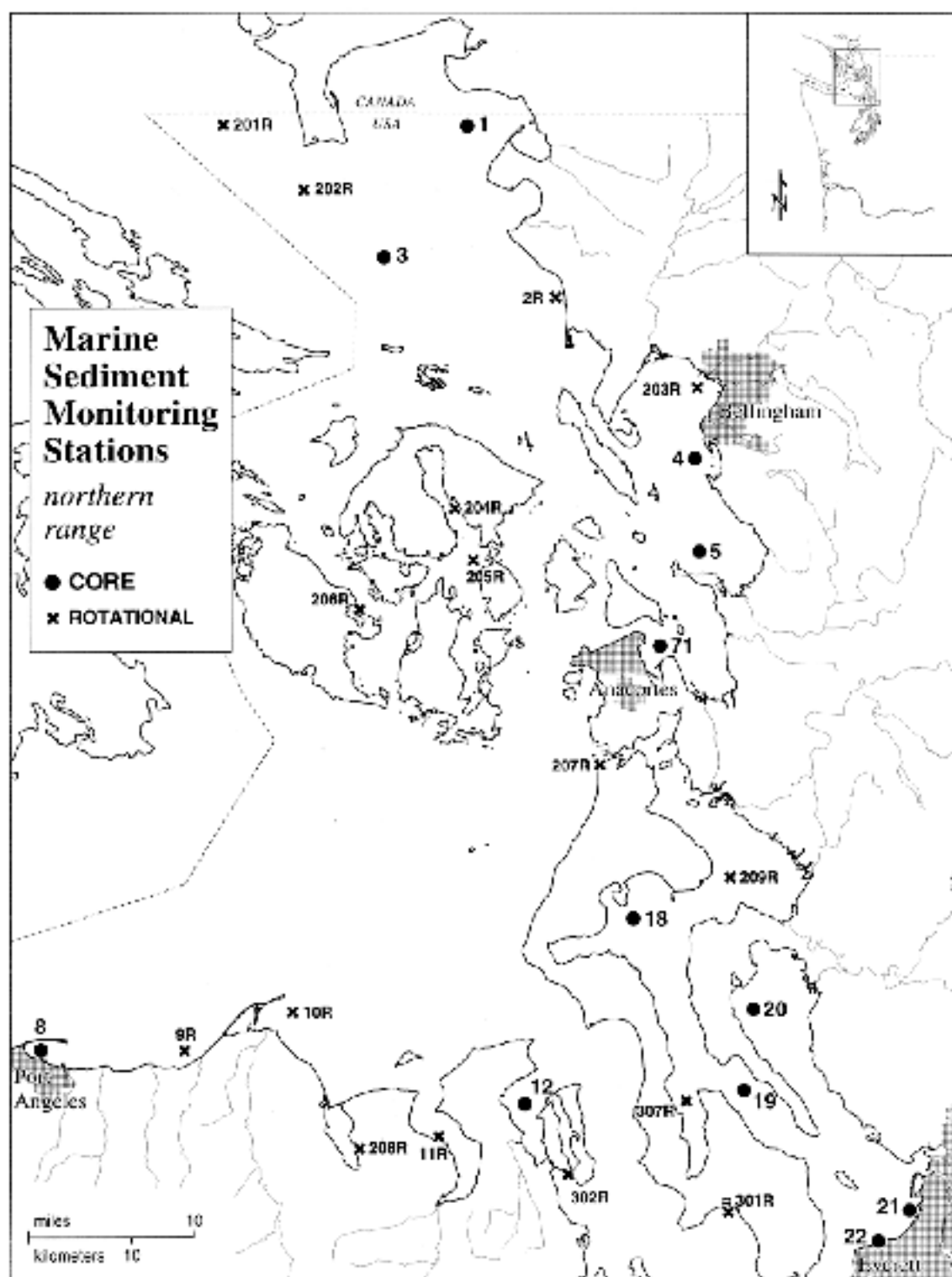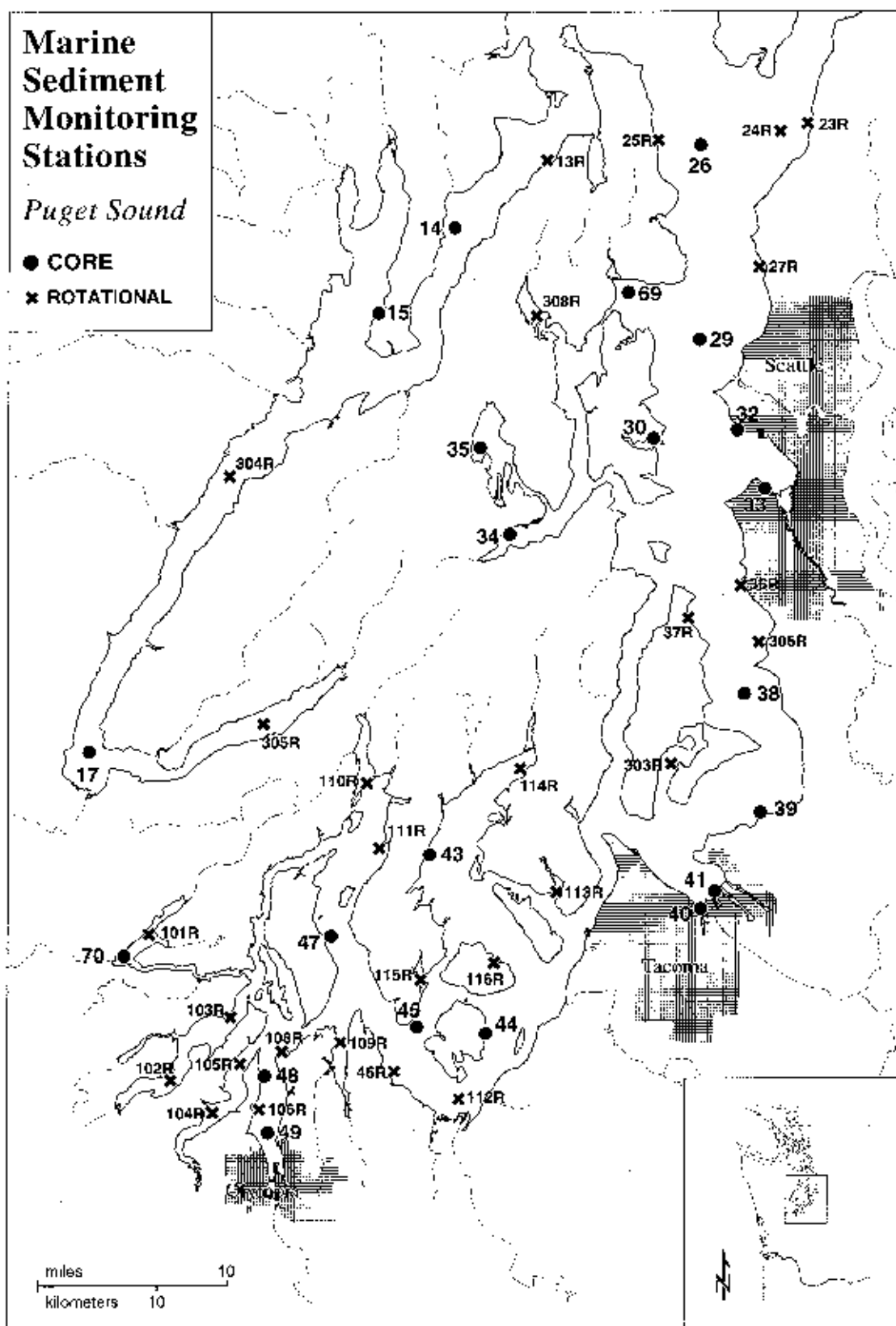
Figure 1. Map of station locations, northern range.

Figure 2. Map of station locations, southern range.

Spatial trends in species distributions were analyzed using numerical classification. Forty-one to 48 stations for each of five years were analyzed using the computer program COMPAH (Eugene Gallagher, Environmental Science Program, University of Massachusetts, Boston, MA). Both normal (by station) and inverse (by species) classifications were produced. The Canberra metric coefficient (Lance and Williams, 1966) and Group Average method (Sneath and Sokal, 1973) were used. Data were transformed to log (x+1).

In cluster analysis, and for each taxon and year, records with more than one level of identification were treated according to a "40% rule." If the abundance at a higher level of identification (e.g., genus) was less than 40% of the combined abundance of this and the next lower level (e.g., species), the lower level of identification was kept in the analysis and the higher level removed. Otherwise, the lower level of identification was merged to the higher level. In addition, taxa occurring below 1% of the total station abundance at all stations were eliminated from the analysis.

Using this last procedure, 63–66% of the taxa were eliminated from the analysis. These taxa, however, represented only 3–5% of the total abundance, and many were sampled infrequently in Puget Sound.

Also, analysis of station by species coincidence tables ("nodal analysis," not presented here) was used to relate the groups derived from normal and inverse classifications (Williams and Lambert, 1961; Boesch, 1977). Benthic measures were summarized and dominant species ranked for each of four categories of stations identified in the cluster analysis.

Results

Sediment Characteristics

Sediments sampled in Puget Sound were classified according to the proportion of sand, silt, and clay. The ranges used to classify the sediments were based on the grouping of stations in the classification analysis (see below). Three classes of sediments were distinct in the analysis: sands, >62% sand and low amounts of clay (<13%); mixed, 20–68% sand and up to 23% clay; and clays, typically ≤20% sand and higher amounts of clay (20–55%).

These three classes of sediments did not have sharp boundaries, but overlapped at both ends of their ranges. For example, some stations with a proportion of clay in the range 20–23% could be classified either as mixed or as clay. These stations, however, were primarily associated with either clay or mixed-type stations in the dendogram depending on their relative proportions of sand, silt, and clay.

Total organic carbon (TOC) ranged from 0.1–4.0%. Most sandy (98%) and mixed (82%) sediments had low TOC concentrations (≤1.5%). High TOC concentrations (>2.5%) were measured at stations where wood from log storage operations has accumulated in sediments, and at inlet ends in south Puget Sound.

Total sulfide concentrations >100 mg/kg were measured in some terminal inlets and semi-enclosed bays, or in areas associated with large freshwater plumes. In all these areas, density stratification is likely to restrict mixing of the water column, and hence, replenishment of dissolved oxygen (DO) to bottom waters.

Diversity

Species Richness (SR) remained relatively constant across years for most stations. Rankings for SR values across years were highly concordant (Kendall coefficient of concordance). Some stations (Table 1) had consistently low species richness (SR<7.0). These stations also exhibited benthic abundance that was significantly lower (ANOVA, $p<0.05$) than stations elsewhere.

Table 1. Puget Sound stations with Margalef's Species Richness values below 7.0 by year, in rank order from low to high. The number of species at these stations was generally below 50, which represents 30% of the species recorded at the station with the highest species richness in Puget Sound. Note that the same core stations (sampled annually and designated with a number <100) appear in the list for most years. Also, the same rotating stations (sampled on a three-year rotation and designated with a number >100 and the letter "R") in south Puget Sound (100R-series) appear in the list in 1990 and 1993.

1989		1990		1991		1992		1993	
49	Inner Budd Inlet	3	Strait of Georgia	208R	Sequim Bay	305R	Lynch Cove	110R	Inner Case Inlet
17	S. Hood Canal	102R	Inner Totten Inlet	17	S. Hood Canal	17	S. Hood Canal	1	Semiahmoo Bay
1	Semiahmoo Bay	49	Inner Budd Inlet	70	Oakland Bay	307R	Holmes Harbor	104R	Inner Eld Inlet
		17	S. Hood Canal	204R	East Sound	70	Oakland Bay	17	S. Hood Canal
		106R	Mid Budd Inlet	49	Inner Budd Inlet	49	Inner Budd Inlet	114R	Henderson Bay
		104R	Inner Eld Inlet	1	Semiahmoo Bay	304R	Tekiu Point	49	Inner Budd Inlet
		1	Semiahmoo Bay	9R	Green Point	1	Semiahmoo Bay	102R	Inner Totten Inlet
		110R	Inner Case Inlet	3	Strait of Georgia	38	Point Pully	48	Outer Budd Inlet
		109R	Henderson Inlet	48	Outer Budd Inlet	48	Outer Budd Inlet	106R	Mid Budd Inlet
		114R	Henderson Bay			3	Strait of Georgia	109R	Henderson Inlet
		101R	N. Oakland					3	Strait of Georgia
		70	Oakland Bay					101R	N. Oakland Bay
		48	Outer Budd Inlet					38	Point Pully
								70	Oakland Bay

Stations with low evenness (J'<0.5), or showing fluctuations in J' values >0.15, reflected the numerical dominance of typically 20 species of benthic organisms plus the Phoronida (Table 2). Some of these species respond to organic enrichment, and because of opportunistic life-history strategies, may show large increases or decreases in abundance. The numerical dominance of these species at some locations may provide information about natural or human-related organic inputs to Puget Sound. One such species, the cirratulid polychaete *Aphelochaeta* sp., is discussed below in this context.

Table 2. Numerically dominant species in Puget Sound responsible for low evenness (J'<0.50) or fluctuations in evenness at the listed stations. A= Amphipoda, B= Bivalvia, C= Cumacea, D= Decapoda, E= Echinodermata, O= Ostracoda, P= Polychaeta, S= Sipuncula.

Species	Station
Amphiodia urtica-periercta (E)	1 Semiahmoo Bay, 35 Dyes Inlet
Aphelochaeta sp. (P)	8 Port Angeles, 30 Eagle Harbor, 35 Dyes Inlet, 41 Commencement Bay
Axinopsida serricata (B)	17 S. Hood Canal, 18 Oak Harbor, 41 Commencement Bay
Eudorella pacifica (C)	35 Dyes Inlet, 48 Outer Budd Inlet
Euphilomedes carcharodonta (O)	13R N. Hood Canal, 25R W. Central Basin
Macoma calcarea (B)	3 Strait of Georgia
Macoma carlottensis (B)	24R E. Central Basin, 29 Shilshole, 38 Point Pully
Macoma nasuta (B)	101R N. Oakland Bay
Nephtys cornuta (P)	102R Inner Totten Inlet, 208R Sequim Bay
Paraprionospio pinnata (P)	49 Inner Budd Inlet, 104R Inner Eld Inlet, 305R Lynch Cove
Pectinaria californiensis (P)	19 Saratoga Passage
Phoronida	15 Dabob Bay, 18 Oak Harbor
Phyllochaetopterus prolifica (P)	34 Sinclair Inlet, 35 Dyes Inlet
Pinnixa schmitti (D)	30 Eagle Harbor, 35 Dyes Inlet
Protomedeia grandimana (A)	1 Semiahmoo Bay
Psephidia lordi (B)	13R N. Hood Canal, 25R W. Central Basin, 101R N. Oakland Bay
Spiochaetopterus costarum (P)	18 Oak Harbor
Spiophanes berkeleyorum (P)	18 Oak Harbor
Spiophanes bombyx (P)	9R Green Point, 25R W. Central Basin
Thysanocardia nigra (S)	201R Roberts Bank
Yoldia sp. (B)	3 Strait of Georgia

On average, sand substrates supported higher number of species and abundance than clay substrates, with deep clay stations having the lowest abundance (Table 3).

Table 3. Abundance (mean number of individuals per 0.1 m^2 grab) and total number of species (five composite 0.1 m^2 grabs) of macrobenthos in Puget Sound. Numbers are averages (±SD) of stations grouped by sediment type over five years (1989–1993) of sampling.

	Sediment Type			
	Sand	Mixed	Clay	Deep Clay
Abundance	527.4 (±245.8)	411.9 (±223.2)	331.3 (±216.7)	189.3 (±124.6)
Number of Species	118.1 (±28.1)	83.0 (±21.2)	53.4 (±18.4)	52.4 (±12.0)

Similarities Among Stations

Classification analyses of stations are illustrated here for two years (Figures 3–4). The results from these analyses showed consistent patterns of spatial variation. These patterns could be explained primarily on the basis of differences in substrate composition and water depth, and secondarily on the basis of differences in species composition between north and south Puget Sound. Sandy stations were separated from clay stations, and generally from mixed stations.

Deep (80–200 m) clay stations formed a distinct group, regardless of location in Puget Sound. Shallow (≤20 m) clay stations were separated into north and south Puget Sound groups. A group of inlet end stations in south Puget Sound was distinct, especially for the two years for which rotating stations were sampled in south Puget Sound. These clusters are identified in bold in Figures 3–4.
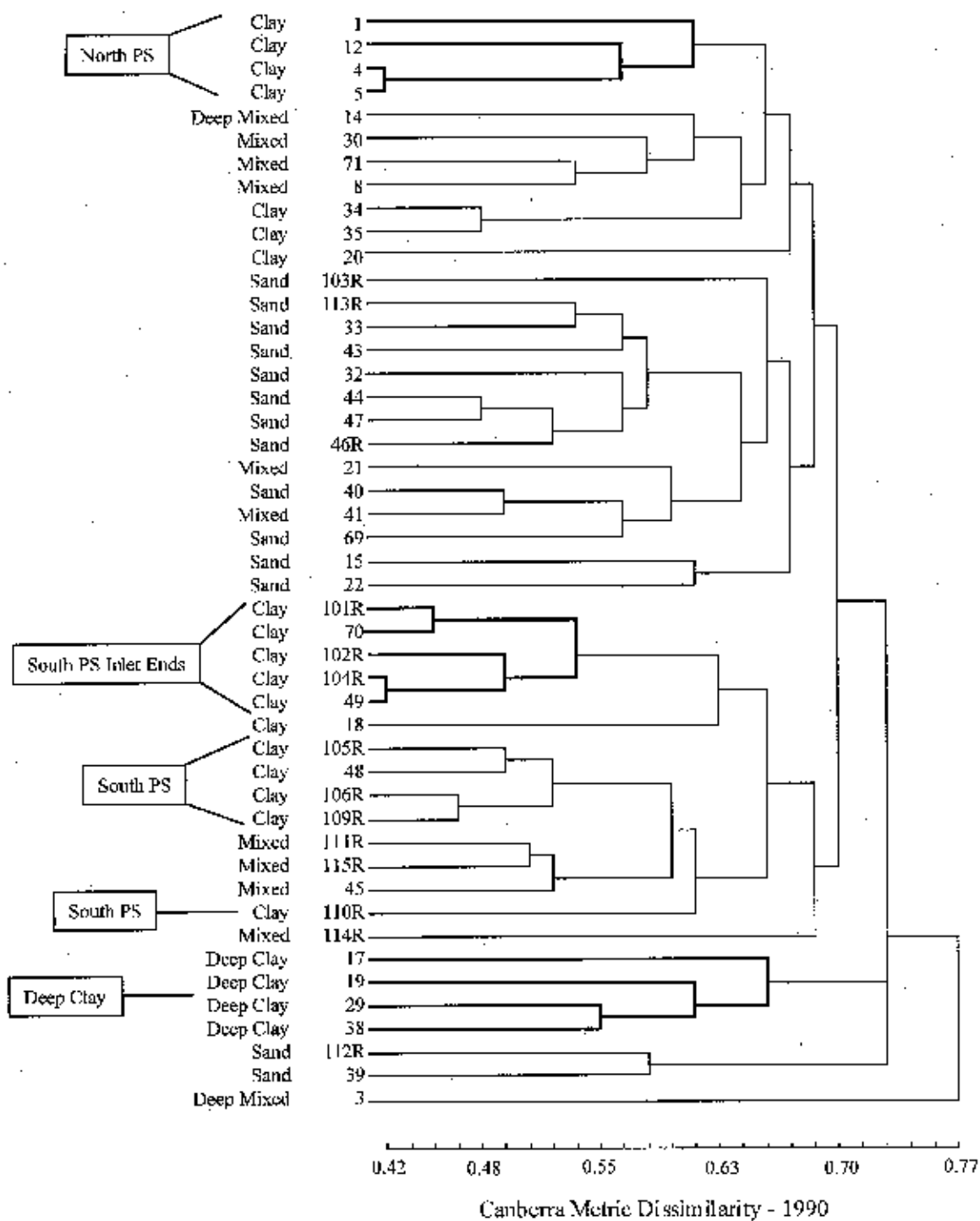
Figure 3. Dendogram showing classification of 47 stations in the Puget Sound region based on mean total abundannce of macrobenthos collected in 1990. Indicated in the dendogram is station number and sediment type.
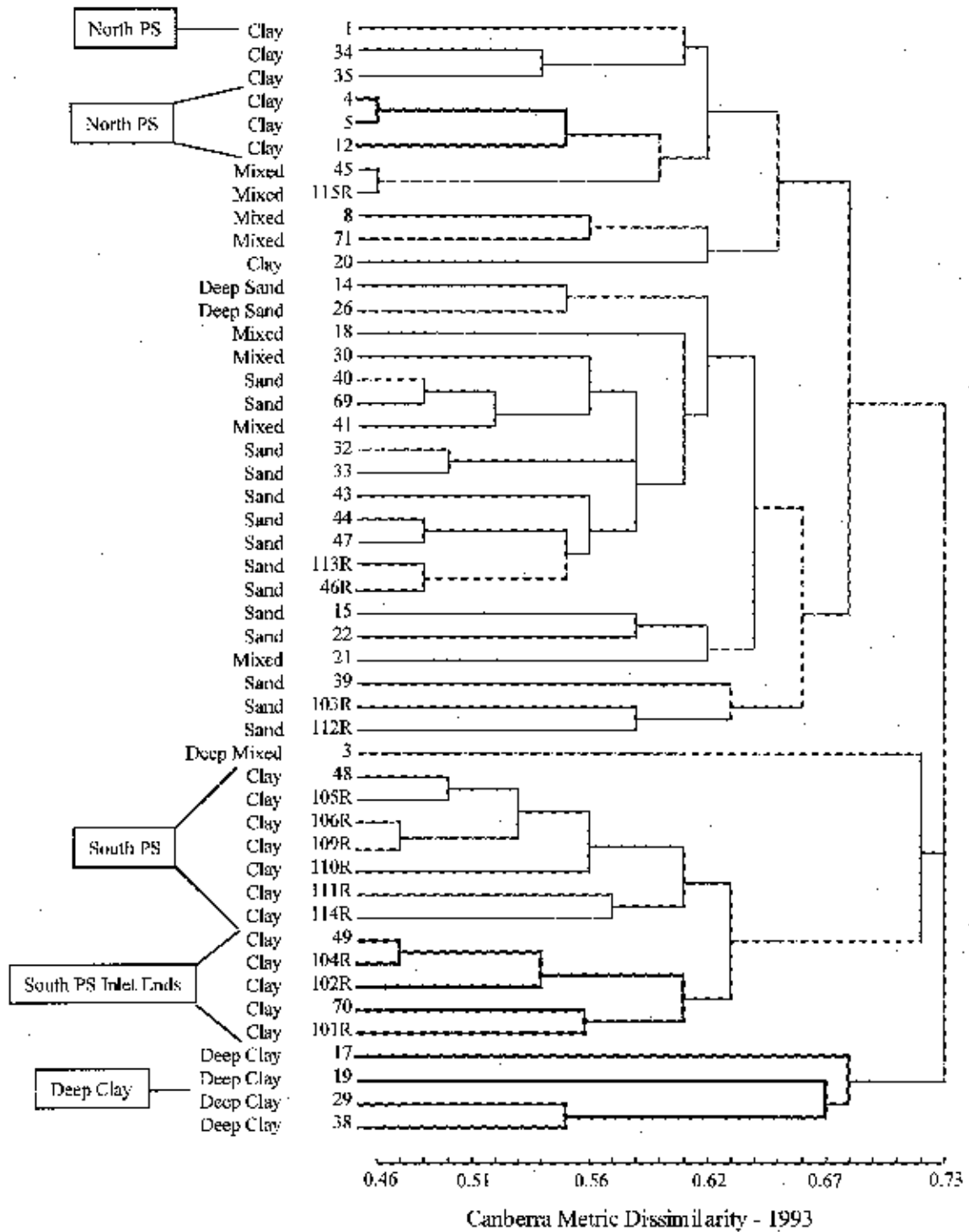
Figure 4. Dendogram showing classification of 48 stations in the Puget Sound region based on mean total abundance of macrobethnos collected in 1993. Indicated in the dendogram is station number and sediment type.

A few stations had low affinity with other stations. Among these, Station 3 in the Strait of Georgia was consistently separated from all others. Also, rotating Stations 305R in Hood Canal, 307R in Holmes Harbor, and 208R in Sequim Bay (not sampled in 1990 or 1993) had low affinity with other stations. These stations showed reduced faunal abundance and low species richness.

Dominant Species

The top numerically dominant species by sediment type are listed in Table 4. The majority of species in Puget Sound were not restricted to one substrate, but were broadly distributed in different types of sediment with peaks of abundance in sand, mixed sediment, or mud. Therefore, benthic infaunal communities in Puget Sound could only be loosely classified according to the type of substrate or water depth in which the species were dominant.

Table 4. Numerically dominant species in Puget Sound by sediment type. B=Bivalvia, C= Cumacea, D= Decapoda, E= Echinodermata, O= Ostracoda, P= Polychaeta.

Sand	Mixed
Euphilomedes carcharodonta (O)	*Axinopsida serricata* (B)
Prionospio jubata (P)	*Aphelochaeta* sp. (P)
Axinopsida serricata (B)	*Eudorella pacifica* (C)
Clay	**Deep Clay**
Amphiodia urtica-periercta (E)	*Macoma carlottensis* (B)
Eudorella pacifica (C)	*Axinopsida serricata* (B)
Sigambra tentaculata (P)	*Pectinaria californiensis* (P)

Some species (e.g., the echinoderms *Molpadia intermedia* and *Brisaster latifrons*) were restricted to deep water, and other species were characteristic of either north (e.g., the polychaetes *Cossura* sp. and *Levinsenia gracilis*) or south (e.g., the polychaete *Sigambra tentaculata*, and the bivalves *Macoma nasuta* and *M. yoldiformis*) Puget Sound clay sediments.

Discussion

The analysis of MSMP stations revealed rich and diverse assemblages of organisms (more than 1,000 species were collected) that were mainly associated with sediment type and water depth, reinforcing results from previous studies (e.g., Lie, 1974). In addition, some assemblages were separated secondarily by geographical location.

One group of stations consisted of inlet ends in south Puget Sound. Inlet ends were characterized by low species richness relative to other locations in Puget Sound. Although there was a tendency for stations with finer substrates to have lower number of species than stations with coarser substrates, clay stations in south Puget Sound supported fewer species than many shallow clay locations elsewhere. In addition, stations in south Hood Canal, Sequim Bay, Holmes Harbor, and the Strait of Georgia (Station 3) exhibited impoverished assemblages and were separated in cluster analysis.

One characteristic common to most of the above locations is their relative physical isolation from main basins that allow water exchange between the Puget Sound region and the continental shelf. Locations of restricted water circulation are prone to the development of seasonal episodes of low DO. If in addition these locations are associated with major inputs of fresh water, the likelihood is for the formation of seasonal density stratification of the water column, which exacerbates the low DO problem with increasing depth. Holmes Harbor and the Strait of Georgia are influenced by the extensive freshwater plumes of the Skagit and Fraser rivers, respectively.

The occurrence of low DO at south Hood Canal, Holmes Harbor, Sequim Bay, and Budd Inlet has been identified by Ecology's Marine Waters Monitoring Program (Newton et al., 1997). Additional data collected by the MSMP in south Hood Canal on two dates in September 1994 have demonstrated an

association between low DO (<2 mg·L^{-1}) and reduced benthic abundance, with the greatest reduction in the crustacea (Llansó, unpublished).

Of course, low DO can only be hypothesized as one factor structuring benthic communities in Puget Sound. A gradual decline in species number is expected to occur along the estuarine gradient, as natural factors such as changes in water circulation, salinity, temperature, and sedimentation rates impose physiological and ecological barriers to the establishment of species populations.

Of special interest in monitoring programs are the relationships between indicator species and locations impacted by pollution. In the MSMP, the cirratulid *Aphelochaeta* sp. (mostly sp. C) was a dominant member of the community at urban stations where organic enrichment and/or moderate contamination were identified. For example, *Aphelochaeta* was numerically dominant near the City of Tacoma wastewater treatment plant WWTP outfall in Commencement Bay (Figure 5). However, elevated densities of this species were not found in any residential or rural areas, as illustrated for Quartermaster Harbor. Other monitoring programs in Puget Sound have found high densities of *Aphelochaeta* in contaminated areas, such as the Hylebos Waterway and the Harbor Island Superfund sites (Figure 5). The association of this species with organic pollution may be useful as an indicator of environmental conditions in Puget Sound.

Conclusions

Puget Sound exhibits rich infaunal assemblages that are primarily associated with sediment type and water depth, and secondarily with geographical location.

- Patterns in species abundance and composition appeared to be unrelated to low or moderate contaminant concentrations at sampling locations. Instead, there was an association between low abundance or species number and locations prone to the development of low-DO episodes.

  The identification of natural stresses in monitoring programs should be made a priority because these factors may confound interpretation of pollution effects.

- Twenty species showed large increases or decreases in abundance. The association of one of these species (*Aphelochaeta* sp.) with sediment contamination and organic enrichment may be useful as indication of pollution. Other pollution tolerant/sensitive species in the Puget Sound region should be identified.

- This study represents the first system-wide effort to characterize benthic assemblages in the Puget Sound region (Olympia north to the Canadian border and west to Port Angeles), and constitutes a first step toward the development of reference standards for assessing benthic environmental conditions in Puget Sound.
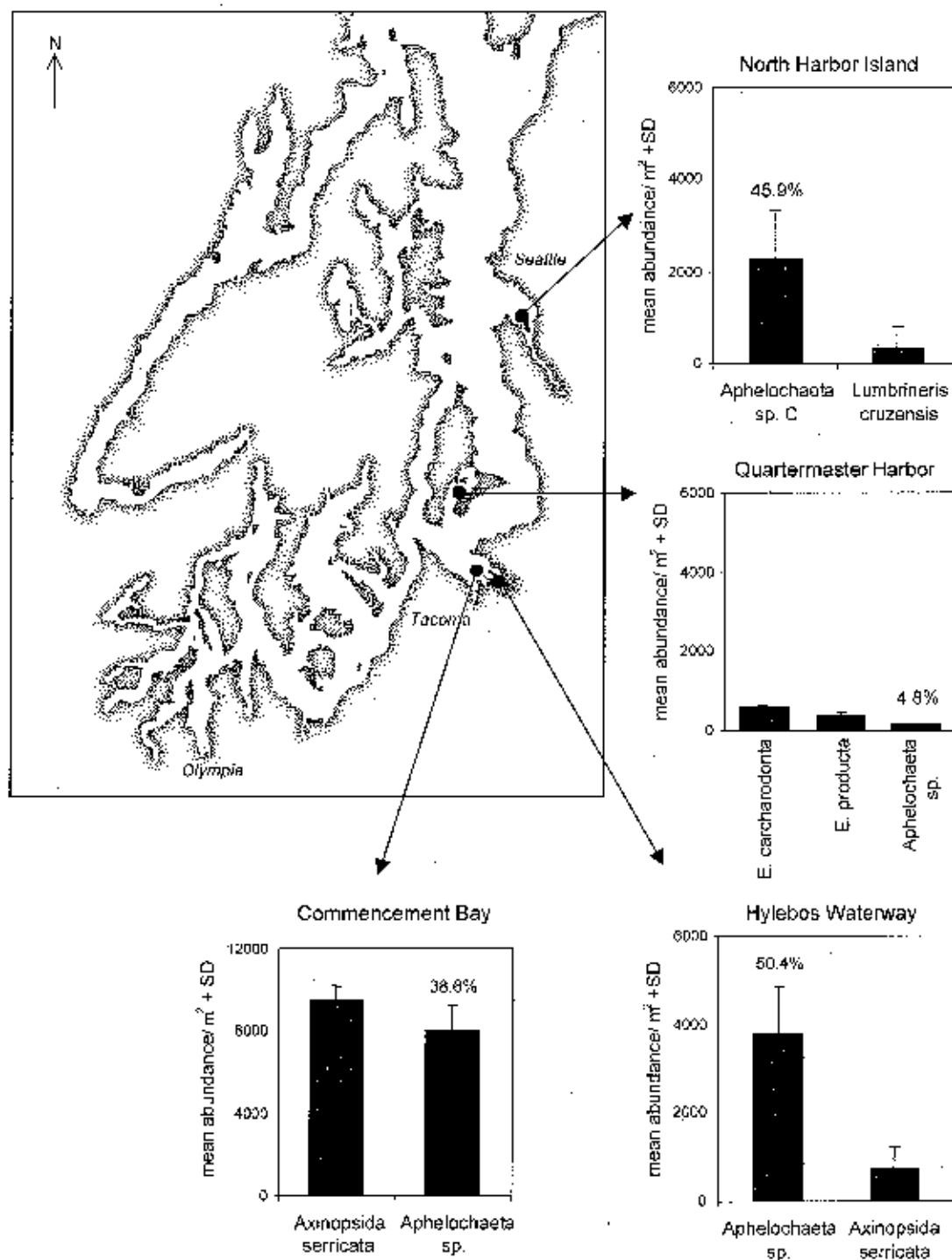
Acknowledgments

Figure 5. Top 2–3 numerically dominant species at four sites in Puget Sound. The percent contribution of the polychaete *Aphelochaeta* sp. to the total station abundance is indicated in the plots. Quartermaster Harbor Station 303R is a rural/residential area. Commencement Bay Station 41 is located near the outfall of Tacoma Central wastewater treatment plant. Hylebos Waterway Station 12 and North Harbor Island Station NH-08 are located in heavily contaminated areas. Selected stations have sediments with similar grain-size composition. Hylebos Waterway data collected by NOAA in 1994; North Harbor Island dada collected by EPA's Elliot Bay Action Program in 1985. *Axinopsida serricata* is a bivalve, *Euphilomedes carcharodonta* and *Euphilomedes producta* are ostracods, and *Lumbrineris cruzensis* is a polycheate.

770

References

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. Va. Inst. Mar. Sci. Spec. Sci. Rept. No. 77.

Chapman, P.M., and E.R. Long. 1983. The use of bioassays as part of a comprehensive approach to marine pollution assessment. Mar. Pollut. Bull. 14:81–84.

Lance, G.N., and T.W. Williams. 1966. A generalized sorting strategy for computer classifications. Nature 212:218.

Lie, U. 1974. Distribution and structure of benthic assemblages in Puget Sound, Washington, USA. Mar. Biol. 26:203–223.

Llansó, R.J., S. Aasen, and K. Welch. 1998. Marine Sediment Monitoring Program: I. Chemistry and Toxicity Testing, 1989–1995. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Olympia, WA.

Margalef, R. 1958. Information theory in ecology. Gen. Syst. 3:36–71.

Newton, J.A., S.L. Albertson, and A.L. Thomson. 1997. Washington State Marine Water Quality in 1994 and 1995. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Olympia, WA.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13:131–144.

Sneath, P.H.A., and R.R. Sokal. 1973. Numerical Taxonomy. The Principles and Practice of Numerical Classification. W.H. Freeman, San Francisco, CA.

Williams, W.T., and J.M. Lambert. 1961. Nodal analysis of associated populations. Nature 191:202.

---

[1] This paper is based on a poster presentation, and represents a partial summary of a more detailed monitoring report in preparation.

[2] Station locations provided upon request.